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(71)
SIEMENS AKTIENGESELLSCHAFT,
Wittelsbacherplatz 2, MšNCHEN, XX (DE).

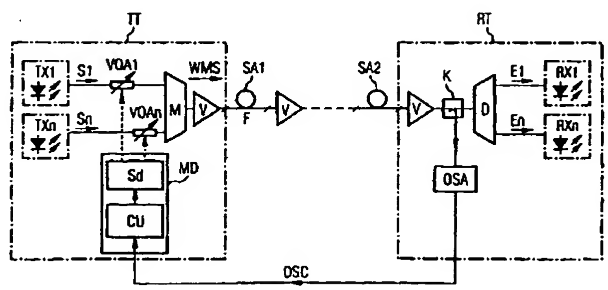
(72)
WEISKE, CLAUS-JORG (DE).
KRUMMRICH, PETER (DE).

(74)
FETHERSTONHAUGH & CO.

(54) PROCEDE DE REGLAGE PAR CANAL DE PUISSANCES DE SIGNAUX D'EMISSION D'UN SYSTEME DE TRANSMISSION A MULTIPLEXAGE PAR REPARTITION EN LONGUEUR D'ONDE

(54) METHOD FOR CHANNEL-BY-CHANNEL ADJUSTMENT OF THE TRANSMITTED SIGNAL POWER LEVELS IN A WAVELENGTH-DIVISION MULTIPLEX TRANSMISSION SYSTEM

(57)
The corresponding transmission signal power levels (Ptx(i)) are adjusted for exact level balance or signal-to-noise ratio balance of received signals (E1 to En). If the dynamic range is surpassed, individual transmission signal outputs are compressed, wherein the transmission signal summation power is maintained at least at an almost constant level.



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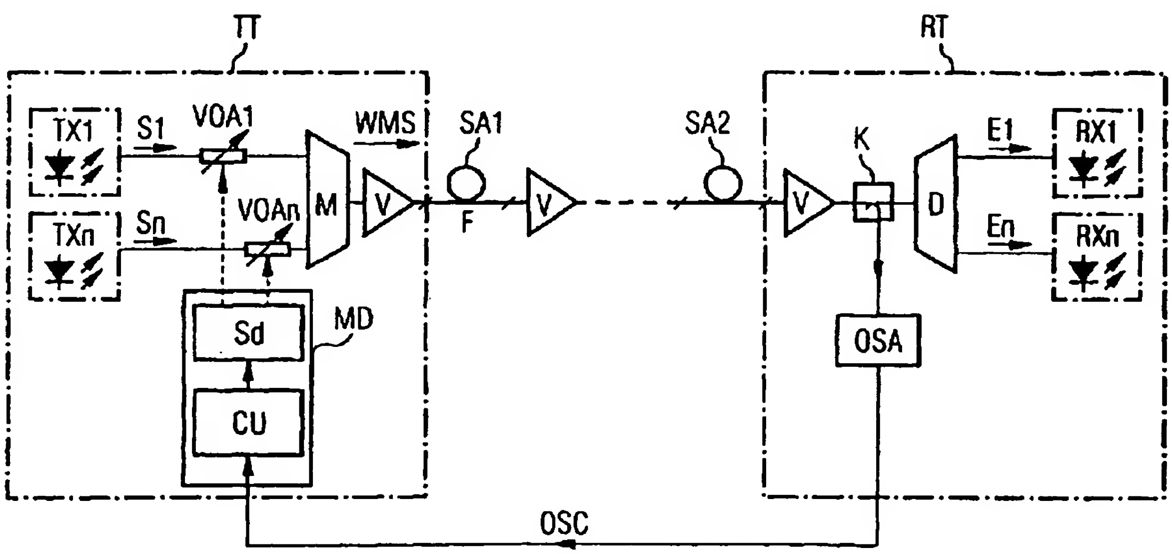
(71) Demandeur/Applicant:
SIEMENS AKTIENGESELLSCHAFT, DE

(72) Inventeurs/Inventors:
KRUMMRICH, PETER, DE;
WEISKE, CLAUS-JORG, DE

(74) Agent: FETHERSTONHAUGH & CO.

(54) Titre : PROCEDE DE REGLAGE PAR CANAL DE PUISSANCES DE SIGNAUX D'EMISSION D'UN SYSTEME DE TRANSMISSION A MULTIPLEXAGE PAR REPARTITION EN LONGUEUR D'ONDE

(54) Title: METHOD FOR CHANNEL-BY-CHANNEL ADJUSTMENT OF THE TRANSMITTED SIGNAL POWER LEVELS IN A WAVELENGTH-DIVISION MULTIPLEX TRANSMISSION SYSTEM



(57) Abrégé/Abstract:
The corresponding transmission signal power levels (Ptx(i)) are adjusted for exact level balance or signal-to-noise ratio balance of received signals (E1 to En). If the dynamic range is surpassed, individual transmission signal outputs are compressed, wherein the transmission signal summation power is maintained at least at an almost constant level.

Abstract

Method for channel-by-channel adjustment of the transmitted signal power levels in a wavelength-division multiplex transmission system

For exact level balancing or signal-to-noise ratio balancing of received signals (E1 to En), the associated transmitted signal power levels (Ptx(i)) are adjusted. If the maximum permissible dynamic range is exceeded, the individual transmitted signal power levels are compressed, with the total transmitted signal power level being kept at least approximately constant.

Figure 1

Description

Method for channel-by-channel adjustment of the transmitted signal power levels in a wavelength-division multiplex transmission system

Owing to the wavelength dependency of optical amplifiers, optical wavelength-division multiplex transmission systems have losses in the transmission fibers and in passive optical components as well as attenuation levels which differ due to non-linear effects such as signal coupling resulting from stimulated Raman scatter in general for the various signals and channels. In an optical transmission path which comprises a number of path sections having a number of fiber amplifiers, these effects can become additive. As a consequence of this, at the receiving end, the weaker optical signals are no longer detected without faults by the optical receiver since their levels are too low or since their optical signal-to-noise ratio (OSNR) is too low. On the other hand, the maximum permissible input level of the optical receiver may be exceeded by a signal which is attenuated to a lesser extent.

One method, which is used in existing optical transmission systems, for compensating for the different levels or OSNR values is corresponding initial compensation at the transmission end, which is referred to as preemphasis. In this case the level or OSNR distribution of the channels/signals at the reception end is measured using an optical spectrum analyzer, and the level at the transmission end is raised for signals which arrive with severe attenuation at the receiver, while the level of more powerful signals is correspondingly reduced, to ensure that all the received signals have the same power level (level balance) or the same signal-to-noise ratio (OSNR balance) at the reception end. The raising or lowering of the transmitted signal level for each channel or for

each transmitted signal is generally selected such that the total transmitted signal power level (total of the power levels of all the transmitted signals and

of the total signal) remains unchanged at the start of the optical path, or does not exceed a maximum value.

Suitable algorithms for level and OSNR balancing are described in the article Equalisation in Amplified WDM Lightwave Transmission Systems in IEEE Photonics, Technology Letters, Vol. 4, No. 8, August 1992, pages 920 to 922.

However, the following disadvantages can occur if exactly implemented level or OSNR compensation is used: owing to the wavelength dependency of the path loss, complete level balancing for the reception end can lead to an excessively high level dynamic range at the transmitting end, that is to say an excessively large quotient between the maximum and minimum channel power level. There is then a risk of signals with a raised transmitted power level being distorted by non-linear effects in the fibers and/or of transmitted signals with a greatly reduced level actually falling below the minimum input power level of an optical amplifier, resulting in considerable signal distortion due to noise.

Complete OSNR balancing for the reception end can also lead to an excessive level dynamic range at the transmitting end.

In addition, there is a risk of the maximum permissible input level range of one or more of the connected optical receivers being exceeded or undershot.

A method and an arrangement for adjusting identical signal levels are known from US Patent 5,815,299. In this method, the average level of all the transmitted signals and the level of the weakest signal are determined. The other signals are attenuated as a function of the difference between the average level and the level of the weakest signal (column 6, lines 56 - 67). However, this reduces the average level and thus the quality of all the other channels. Such a method admittedly leads to identical levels in all the

channels, but does not optimally utilize the maximum possible dynamic range and thus does not achieve optimum transmission quality or optimum range.

The object of the invention is thus, for wavelength division multiplex systems, to specify a method for channel-by-channel adjustment of transmitted signal power levels, in which the transmission-end dynamic range is complied with without unnecessarily adversely affecting the transmission quality. An extended method also takes account of the reception-end dynamic range for exact OSNR balancing.

The object is achieved by methods which are specified in the independent claims 1 and 4.

Advantageous developments of the invention are specified in the dependent claims.

In general, exact level balancing at the reception end is not required, since the connected optical receivers have a considerable level dynamic range in which they operate optimally. In the same way, exact OSNR balancing is not required, provided appropriate system margins are available. In this case, a method is optimal which considers only the dynamic range of the transmitted signals. Since, in general, the systems operate at an optimum or maximum permissible total power level, it is advantageous for this level to remain constant in any compression of the individual transmitted signal power levels which may be required.

However, for OSNR balancing, the maximum permissible dynamic range at the reception end must also be checked. If necessary, the received signal power levels are adapted by compression. This is once again done by changing the power level of the individual transmitted signals. In this case as well, compliance with the transmission-end dynamic range must be checked once again and, if necessary, changed.

The invention will be explained in more detail with reference to an exemplary embodiment. In the figures:

Figure 1 shows an exemplary embodiment of a WDM transmission system with dynamic range compression,

Figure 2 shows a flowchart for transmission-end dynamic range compression, and

Figure 3 shows a flowchart for reception-end dynamic range compression.

Figure 1 shows the outline circuit diagram of a WDM transmission device. A transmission terminal TT contains

a number of optical transmitters TX1 to TXn for transmitting data via channels allocated to different wavelengths. The corresponding transmitted signals S1 to Sn are passed via adjustable optical attenuators VOA1 to VOAn, and are combined by a multiplexer M to form a wavelength-division multiplex signal WMS. This signal is fed into an optical fiber F and is transmitted via various path sections SA1, SA2 to a receiving terminal RT. Various optical amplifiers V are provided in order to compensate for the attenuation by the optical fibers. In the receiving terminal RT, the wavelength division multiplex signal is broken down in a demultiplexer D into individual received signals E1 to En, which are supplied to a respective optical receiver RX1 to RXn.

The wavelength division multiplex signal is split at the reception end by a coupler K, which is connected upstream of the demultiplexer, and is supplied to an optical spectrum analyzer OSA. The level and OSNR values measured by this optical spectrum analyzer OSA are passed - for example via a separate control channel OSC (Optical Supervisory Channel) - to a preemphasis controller MD in the transmission terminal. This comprises a computation device CU and an adjustment device SD which adjusts the transmitted levels of the individual transmitted signals, for example by controlling the output power level of the optical transmitters or, in this case, by adjusting the attenuators. The computation unit can likewise be provided at the reception end.

First of all, let us consider the situation in which only the transmission-end dynamic range is adjusted, on the basis of the flowchart in **Figure 2**. The individual transmitted power levels and received power levels or transmitted power levels and reception-end signal-to-noise ratios, for short the attenuations in the individual channels or the OSNR quality (signal to noise ratio/transmitted power level) generally need to be known by measurements.

Firstly, the transmission-end power distribution (level distribution) is then calculated for exact level or OSNR balancing at the reception end, based on the transmission characteristics of the individual channels, as described above.

The dynamic range compression can then be started. A first step determines the magnitude of the transmission-end level dynamic range Dtx. This corresponds to the quotient of the maximum level Ptx_max and the minimum level Ptx_min of the transmitted signals, with the term level in this case meaning the power on a linear scale, for example in milliwatts.

F1) Dtx = maximum level from Ptx(i)/minimum level from Ptx(i)
i = 1, 2, ... n - Transmitted signal

A check is then carried out to determine whether the dynamic range Dtx which has been found is greater than the maximum permissible dynamic range Dtx_max. If this is not the case, no dynamic range compression is carried out. However, if this is the case, the next computation step calculates the discrepancy, that is to say the offset, of the individual signal power levels from the mean value Ptx_mean, which has been determined from the optimum or maximum permissible transmitted power level of the transmission-end wavelength division multiplex signal divided by the number of signals.

F2) deltaP_tx(i) := Ptx(i) - Ptx_mean

The next computation step determines the absolute maximum and minimum offset, in other words the offset of the strongest and weakest transmitted signal.

F3) deltaPtx_max := max(deltaPtx(i))
deltaPtx_min := min(deltaPtx(i))

The transmission compression factor is then calculated

F4) compfact_tx := Ptx_mean* (Dtx_max - 1)/
(deltaPtx_max - Dtx_max*deltaPtx_min)

This is then used to calculate the compressed levels using the following formulae:

F5) deltaPtx(i) := deltaPtx(i) * compfact_tx
Ptx(i) := Ptx_mean + deltaP_tx(i)

The dynamic range compression has thus already been calculated and the newly calculated compressed transmission levels Ptx(i) of the transmitted signals S1 to Sn can be set.

If the individual received signals E1 to En are intended to have the same signal-to-noise ratio, that is to say OSNR balancing is assumed, reception-end dynamic range compression can also be carried out, in an extended method as shown in **Figure 3.** The compression method is once again dependent on the transmission characteristics of each channel being known.

This makes it possible to calculate the transmission-end levels for the individual transmitted signals, the level distribution, for OSNR balancing.

The reception-end dynamic range compression starts by determining the reception-end dynamic range Drx.

F7) Drx:= maximum level from Prx(i)/minimum level from Prx(i)
i = 1, 2, ...,n - Received signal

A check is then carried out to determine whether the maximum permissible reception-end dynamic range Drx is exceeded. If not, there is no need for reception-end dynamic range compression, and the

calculated signal levels can be set at the transmission end. In general, a check of the maximum permissible transmission-end dynamic range is also required.

If, on the other hand, the maximum permissible reception-end dynamic range Drx is exceeded, then, first of all, the discrepancies, the offsets, of the reception-end channel power levels Ptx(i) from the main value Ptx_mean are established:

F7) deltaP_rx(i) := P_rx(i) - P_rx_mean

and the maximum and minimum offsets are determined:

F8) deltaP_rx_max :=max(deltaP_rx(i))
    deltaP_rxmin := min(deltaP_rx(i))

The reception-end compression factor is then calculated:

F9) compfact_rx :=Prx_mean*(Drx_max - 1)
    /(deltaPrx_max - Drx_max * deltaPrx_min

The compressed reception levels are then determined:

F10) Prx(i) := Prx_mean * deltaPrx(i) * compfact_rx

The already determined channel-specific path loss Atten(i) can now be used to determine the associated transmission levels from the compressed reception levels:

F11) Ptx_new(i) := Prx(i) * Atten(i)

It may be necessary to reduce the transmission signal power levels if the maximum permissible total power level is exceeded, or it is worthwhile increasing the transmitted signal power levels

in order to improve the transmission characteristics. Both are carried out by new transmission-end level matching.

A new transmission-end mean value will be calculated for this purpose:

F12) Ptx_mean_new = Total (Ptx_new(i)/Number of channels)

This is used to establish a transmission-end correction factor;

F13) corfact_tx = Ptx_mean/Ptx_mean_new

The new transmission levels are then calculated:

F14) Ptx(i) = Ptx_new(i)* corfact_tx

This completes the calculation of the dynamic range compression process, and the newly calculated transmission levels are set.

Signal failures must, of course, be taken into account in the dynamic range compression process. The time constants of the control loop are matched to the requirements.

Patent Claims

1. A method for channel-specific adjustment of transmitted signal power levels in a wavelength-division multiplex transmission system,

in which the transmission characteristics for each transmission channel are determined and

if the signal power levels or the signal-to-noise ratios of the individual received signals (E1 to En) are the same, the signal power levels of the associated transmitted signals (S1 to Sn) are determined on a channel-specific basis,

characterized

in that the transmission-end dynamic range (Dtx) is determined,

in that, if the maximum permissible dynamic range (Dtx_max) at the transmission end is exceeded, the individual power discrepancies (delta Ptx(i), i = 1, 2, ...n) of the transmitted signals (S1 to Sn) from the mean transmitted signal power level (Ptx_mean) are determined and the individual power discrepancies of the transmitted signals (S1 to Sn) are reduced by calculation, using a transmission compression factor (compfact_tx), which is the same for all the transmitted signals (S1 to Sn), in such a manner that the maximum permissible dynamic range is complied with,

in that the required transmission signal power levels (Ptx_new(i)) are recalculated, and

in that the newly calculated compressed transmitted signal power levels (Ptx_new(i)) are set.

2. The method as claimed in claim 1,

characterized

in that the total maximum permissible total transmitted signal power level of all the transmitted signals (S1 to Sn) is kept at least approximately constant.

3. The method as claimed in claim 1 or 2,

characterized

in that the transmitted signal power levels (Ptx(i)) of the transmitted signals (S1 to Sn) and transmission-end

values (Dtx,

delta Ptx(i), Ptx_mean) derived from them are determined by measuring the received signal power levels of the received signals (E1 to En) and from the transmission characteristics of the transmission channels.

4. A method for channel-specific adjustment of transmitted signal power levels in a wavelength-division multiplex transmission systems,

in which the transmission characteristics for each transmission channel are determined and

if the signal-to-noise ratios of the individual received signals (E1 to En) are the same, the power levels (Ptx(i)) of the associated transmitted signals (S1 to Sn) are determined on a channel-specific basis,

characterized

in that the reception-end dynamic range (Drx) is determined,

in that, if the maximum permissible reception-end dynamic range (Drx_max) is exceeded, the individual power discrepancies (delta Prx(i), i = 1, 2, ...n) of the transmitted signal power levels from the mean received power level (Ptx_mean) are determined, and the individual power discrepancies of the received signals (E1 to En) are reduced by calculation using a compression factor (compfact_rx) which is the same for all the received signals (E1 to En), in such a manner that the maximum permissible dynamic range at the reception end is complied with,

in that the required new transmitted signal power levels (Ptx_new(i)) are calculated,

in that, if necessary, transmission-end power correction is carried using a transmission-end correction factor (corfact_tx) which needs to be calculated, and

in that the newly calculated compressed transmission signal power levels (Ptx_new(i); Ptx(i)) are set.

5. The method as claimed in claim 4,

characterized

in that the total received signal power level (Prx_mean) of all the received signals (E1 to En) and/or the total transmitted signal

power level (Ptx_mean) of all the transmitted signals (S1 to Sn) is kept at least approximately constant.

6. The method as claimed in claim 4 or 5, characterized in that the transmitted signal power levels (Ptx(i)) of the transmitted signals (S1 to Sn) and transmission-end values (Dtx, delta Ptx(i), Ptx_mean), derived from them, are determined by measurement of the received signal power levels of the received signals (E1 to En) and from the transmission characteristics of the transmission channels.

7. The method as claimed in claim 6, characterized in that the transmission-end correction factor (corfact_tx) is calculated from the ratio of the previous transmission-end mean level value (Ptx_mean) to a transmission-end mean level value (Ptx_mean_new) determined from the required new transmitted signal power level (Ptx_new(i)), and in that the individual signal power levels (Ptx(i)) of the transmitted signals (S1 to Sn) are changed using this transmission-end correction factor (corfact_tx), which is the same for all the transmitted signals (S1 to Sn), in such a manner that the total maximum permissible total transmitted signal power level of all the transmitted signals (S1 to Sn) is kept at least approximately constant.

Fetherstonhaugh & Co.
Ottawa, Canada
Patent Agents

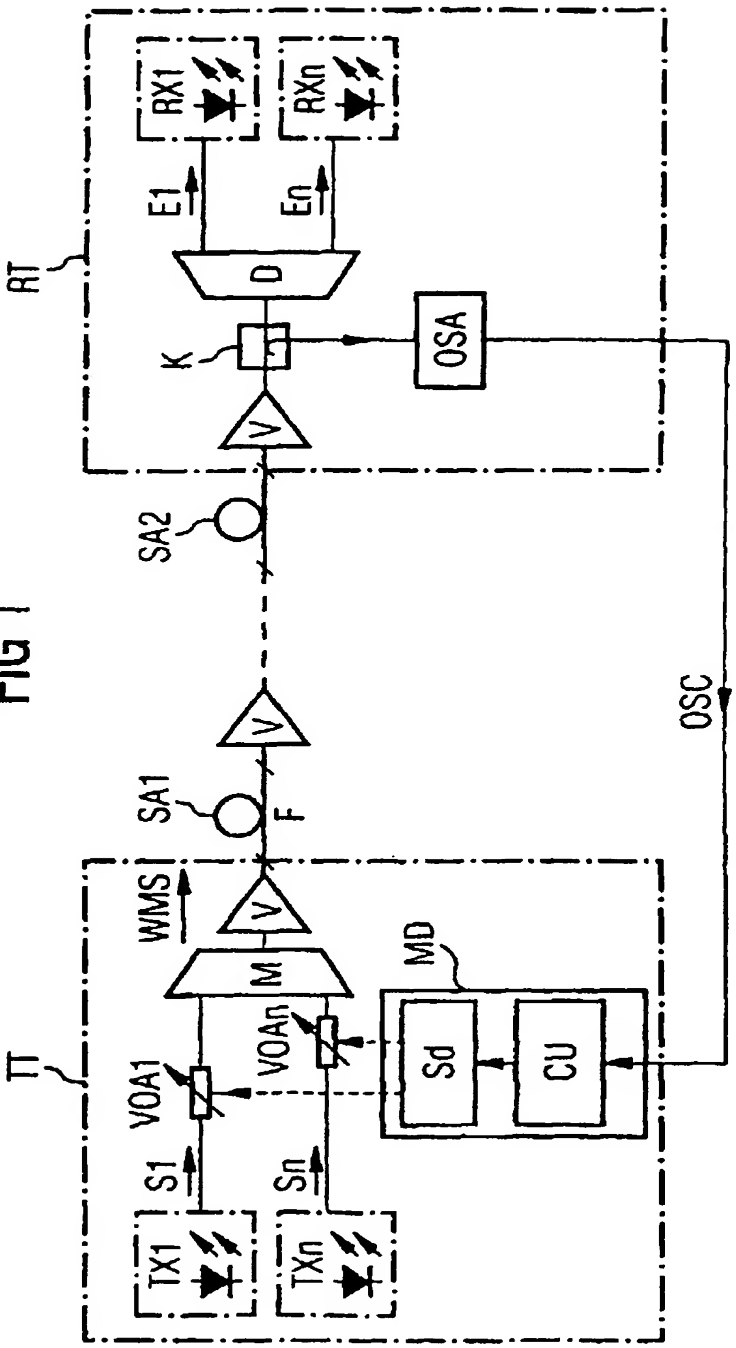

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FIG 1

FIG 2A

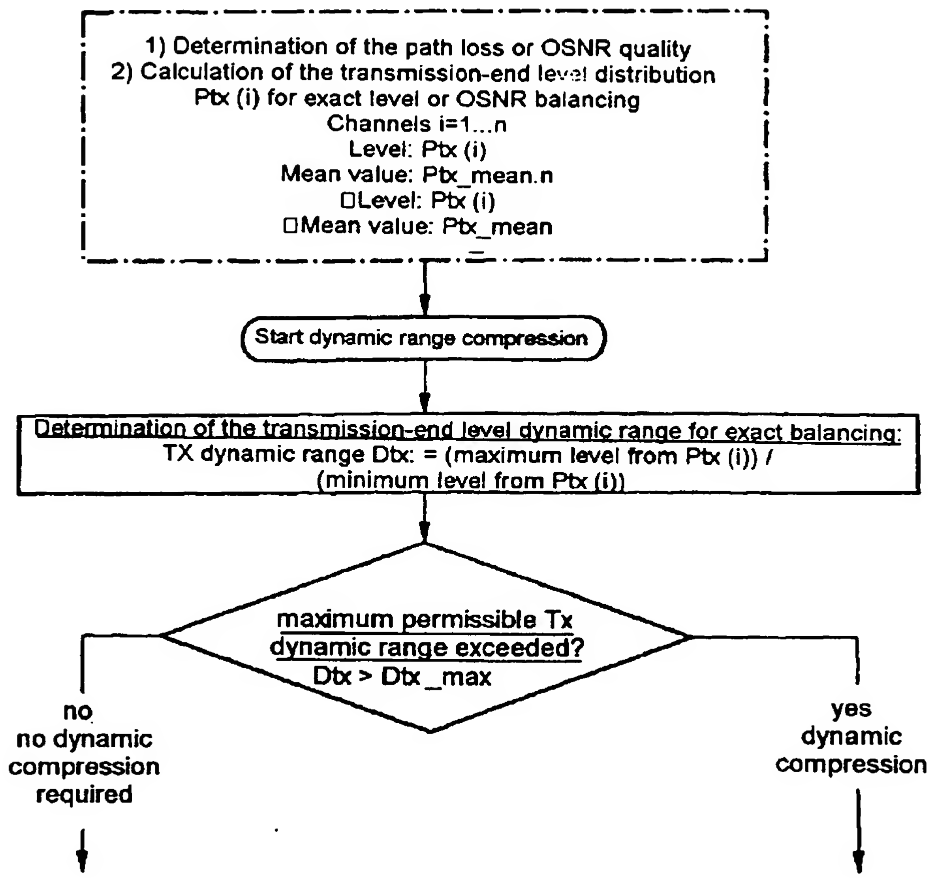

1) Determination of the path loss or OSNR quality
2) Calculation of the transmission-end level distribution
Ptx (i) for exact level or OSNR balancing
Channels i=1...n
Level: Ptx (i)
Mean value: Ptx_mean.n
□Level: Ptx (i)
□Mean value: Ptx_mean
Start dynamic range compression
Determination of the transmission-end level dynamic range for exact balancing:
TX dynamic range Dtx: = (maximum level from Ptx (i)) /
(minimum level from Ptx (i))
maximum permissible Tx
dynamic range exceeded?
Dtx > Dtx_max
no
no dynamic
compression
required
yes
dynamic
compression

FIG 2B

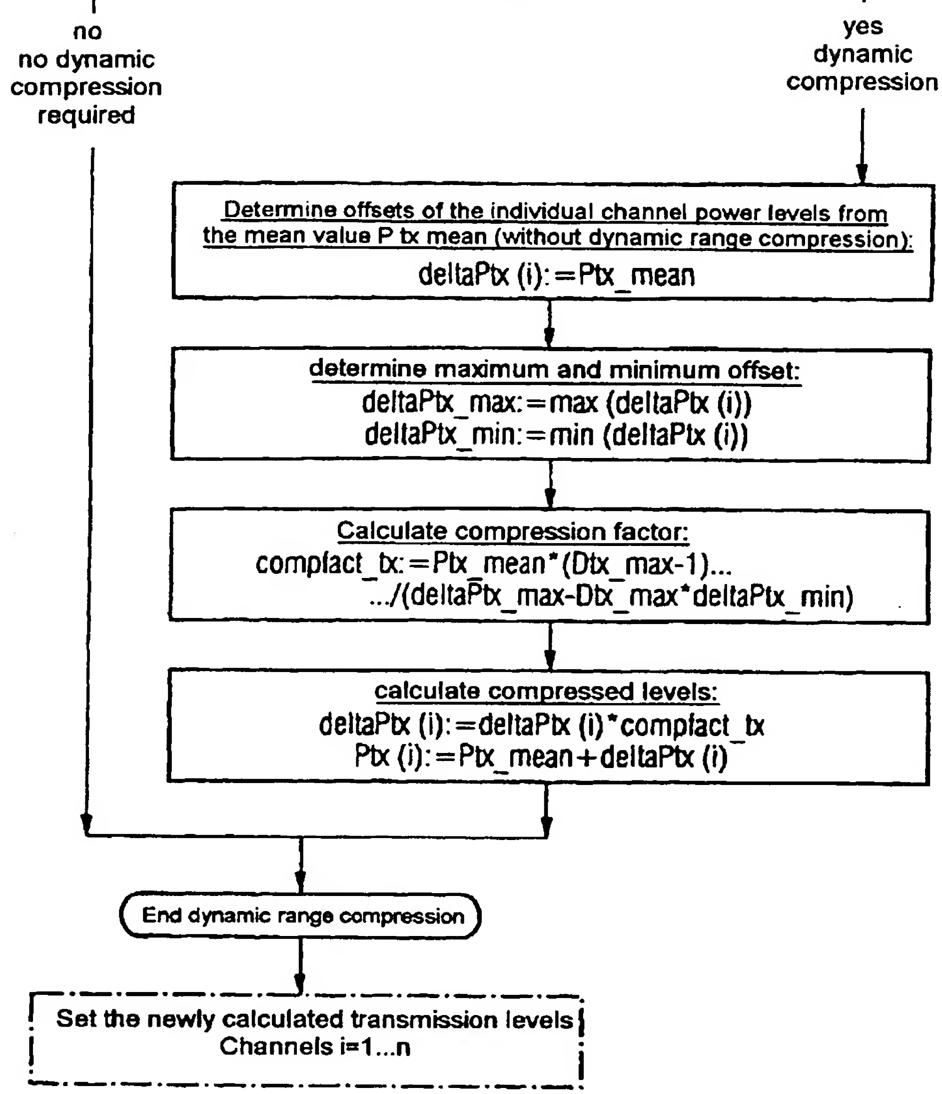

no
no dynamic compression required
yes
dynamic compression
Determine offsets of the individual channel power levels from the mean value P tx mean (without dynamic range compression):
deltaPtx (i):=Ptx_mean
determine maximum and minimum offset:
deltaPtx_max:=max (deltaPtx (i))
deltaPtx_min:=min (deltaPtx (i))
Calculate compression factor:
compfact_tx:=Ptx_mean*(Dtx_max-1)...
.../(deltaPtx_max-Dtx_max*deltaPtx_min)
calculate compressed levels:
deltaPtx (i):=deltaPtx (i)*compfact_tx
Ptx (i):=Ptx_mean+deltaPtx (i)
End dynamic range compression
Set the newly calculated transmission levels
Channels i=1...n

FIG 3A

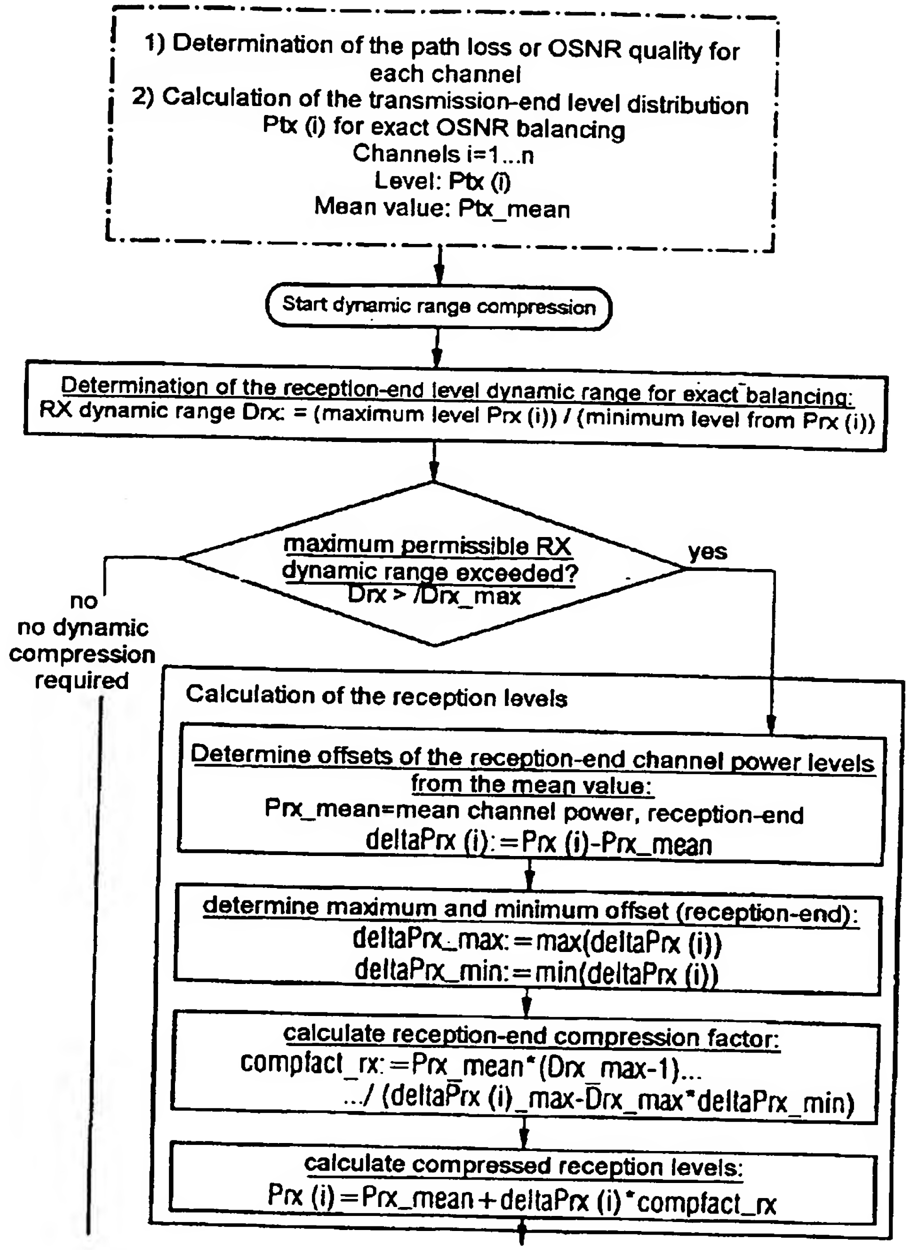
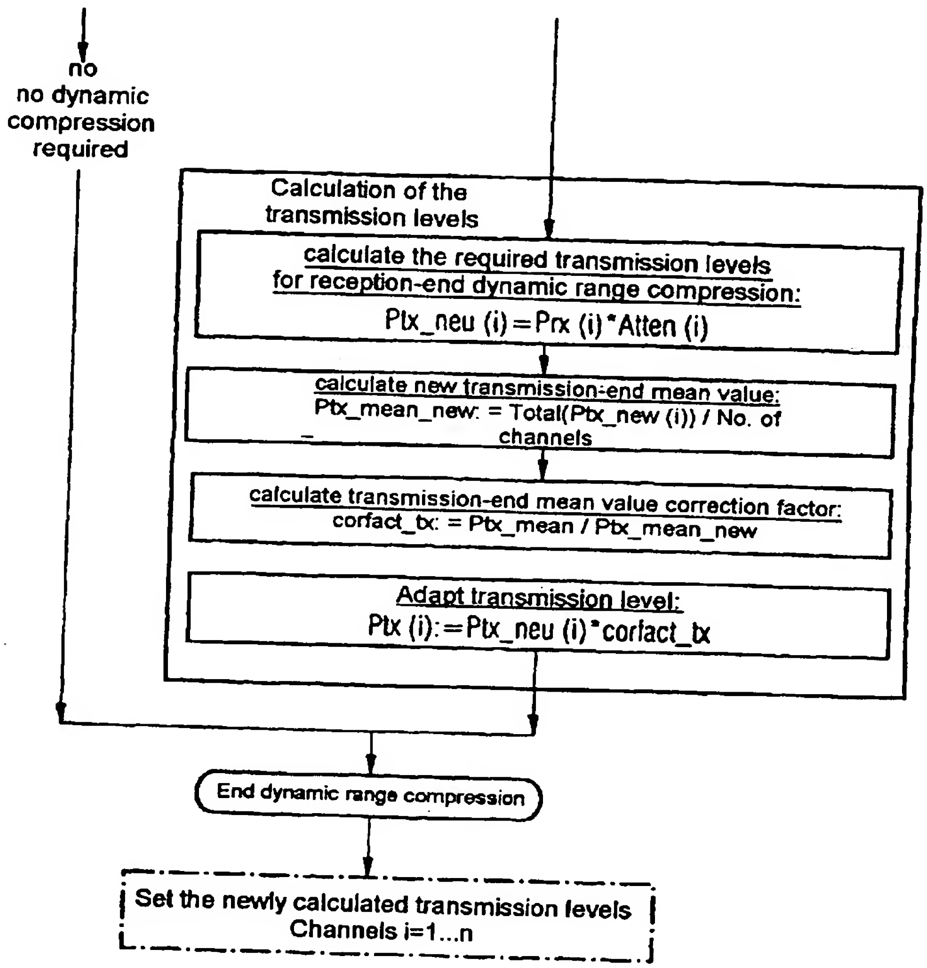

1) Determination of the path loss or OSNR quality for each channel
2) Calculation of the transmission-end level distribution Ptx (i) for exact OSNR balancing
Channels i=1...n
Level: Ptx (i)
Mean value: Ptx_mean
Start dynamic range compression
Determination of the reception-end level dynamic range for exact balancing:
RX dynamic range Drx: = (maximum level Prx (i)) / (minimum level from Prx (i))
maximum permissible RX dynamic range exceeded?
Drx > /Drx_max
yes
no
no dynamic compression required
Calculation of the reception levels
Determine offsets of the reception-end channel power levels from the mean value:
Prx_mean=mean channel power, reception-end
deltaPrx (i):=Prx (i)-Prx_mean
determine maximum and minimum offset (reception-end):
deltaPrx_max:=max(deltaPrx (i))
deltaPrx_min:=min(deltaPrx (i))
calculate reception-end compression factor:
compfact_rx:=Prx_mean*(Drx_max-1)...
.../ (deltaPrx (i)_max-Drx_max*deltaPrx_min)
calculate compressed reception levels:
Prx (i)=Prx_mean+deltaPrx (i)*compfact_rx

FIG 3B


no
no dynamic compression required
Calculation of the transmission levels
calculate the required transmission levels for reception-end dynamic range compression:
Ptx_neu (i)=Prx (i)*Atten (i)
calculate new transmission-end mean value:
Ptx_mean_new: = Total(Ptx_new (i)) / No. of channels
calculate transmission-end mean value correction factor:
corfact_tx: = Ptx_mean / Ptx_mean_new
Adapt transmission level:
Ptx (i):=Ptx_neu (i)*corfact_tx
End dynamic range compression
Set the newly calculated transmission levels
Channels i=1...n